The 50 MHz DX Bulletin

Volume 3 1992 May **Issue #5**

Understanding Solar-Terrestrial Reports

by Cary Oler, Solar Terrestrial Dispatch

If you have access to Internet, Usenet, or Bitnet, you could be reading reports like the following daily instead of requesting "The Numbers" from folks on 28.885.

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DAILY SUMMARY OF SOLAR GEOPHYSICAL ACTIVITY

31 MAY, 1992

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(Based In-Part On SESC Observational Data)

SOLAR AND GEOPHYSICAL ACTIVITY INDICES FOR 31 MAY
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NOTE: Proton fluence data was not available at the time of this report.

!!BEGIN!! (1.0) S.T.D. Solar Geophysical Data Broadcast for DAY 152, 05/31/92
10.7 FLUX=099.0  90-AVG=151         SSN=054       BKI=2412 1222  BAI=008
BGND-XRAY=B1.2     FLU1=*.*E+**  FLU10=*.*E+**  PKI=3321 2222  PAI=009
  BOU-DEV=018,056,009,010,009,013,015,010   DEV-AVG=017 NT     SWF=00:000
 XRAY-MAX= C1.5   @ 2359UT    XRAY-MIN= B1.1   @ 0843UT    XRAY-AVG= B2.3
NEUTN-MAX= +003%  @ 2145UT   NEUTN-MIN= -002%  @ 1715UT  NEUTN-AVG= +0.2%
  PCA-MAX= +0.4DB @ 1740UT     PCA-MIN= -0.1DB @ 1520UT    PCA-AVG= +0.0DB
BOUTF-MAX=55283NT @ 2213UT   BOUTF-MIN=55241NT @ 1656UT  BOUTF-AVG=55270NT
GOES7-MAX=P:+110NT@ 2037UT   GOES7-MIN=N:-002NT@ 0446UT  G7-AVG=+085,+040,+010
GOES6-MAX=P:+125NT@ 2047UT   GOES6-MIN=E:-020NT@ 1708UT  G6-AVG=+098,+004,+030
 FLUXFCST=STD:100,100,100;SESC:100,100,100 BAI/PAI-FCST=010,021,010/012,015,015
    KFCST=2214 4112 4435 5334  27DAY-AP=013,006   27DAY-KP=3423 3312 1211 2222
 WARNINGS=
   ALERTS=
!!END-DATA!!

BRIEF SUMMARY OF EVENTS
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Solar activity remained low. The only C-class flare observed over the last 24 hours was a class C1.5 x-ray event that peaked at 23:59 UT. Several other smaller B-class events were also scattered throughout the day. Perhaps the most impressive of these smaller events was a long-duration (195 minutes) class B6.7/SF parallel-ribbon flare from spotless Region 7178 (S23W46) at 12:28 UT. This event was not accompanied by any significant radio bursts or sweep frequency events.

Region 7185 (N12E13) was the most interesting region observed. It exhibited rapid growth in spot size, but remained fairly small in spatial extent. A strong arch filament system exists in this region, suggesting further growth is likely to be observed over the next 24 to 72 hours. Although flare activity has been confined to B-class levels, C-class flare activity may materialize in short-order if continued growth and development persists.

Other activity of interest included the disappearance of two filaments. The first filament disappeared sometime between 21:15 UT on 30 May and 14:38 UT on 31 May. Prior to the eruption, this filament was approximately 15 degrees long and was centered near N10E60 on 30 May. The second filament erupted near S35W40 and was approximately 10 degrees in length. An active prominence was also observed during the day on the west limb near S15.

No new regions were numbered today.

Solar activity is expected to continue low to very low. At the present time, Region 7185 appears to be the best candidate for spawning minor C-class flare activity. All of the regions are presently small and simple spot groups or areas of plage.

The geomagnetic field was mostly quiet to mildly unsettled. The field is expected to continue generally quiet to unsettled on 01 June. There is a slight chance the field may then become mildly enhanced to unsettled or weakly active levels on 02 June in response to a filament disappearance between 28 and 29 May. Conditions should then stabilize toward quiet levels on 03 and 04 June. If this disturbance fails to arrive, generally quiet to unsettled conditions should dominate.

HF propagation conditions continued near-normal to slightly below normal over all regions. The low solar flux is continuing to prevent reliable propagation on the higher frequencies due to reduced MUFs. Similar conditions are expected over the next 24 to 72 hours. There is a chance polar and high latitude signal paths may experience minor degradation if the filament-related disturbance noted above arrives on 02 June. Otherwise, all regions should observe near-normal propagation.

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** End of Daily Update **
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These Solar Terrestrial Reports are generated and put on the net by Cary Oler, Operations Manager at Solar Terrestrial Dispatch at Stirling, Alberta, Canada. He has written a lengthy guide entitled **Understanding Solar Terrestrial Reports** which I (K6FV) plan to publish serially in The Six Meter Bulletin as space allows. Our editor, Shel, has not submitted a bulletin for May. I believe that our readership deserves at least 12 newsletters a year; e.g., one a month. I trust that this series will meet with your approval.

I have very little to add to Cary's material; but any such additions will be in this typeface. We begin with his Glossary of Solar Terrestrial Terms, which will be followed by Part 1 of his guide, which describes in some detail the connection between events happening on the surface of the Sun and their effect on the Earth.

Glossary of Solar-Terrestrial Terms

The solar terrestrial forecasts which are being distributed over the networks contain some language that may not be very clear to many people unfamiliar with solar terrestrial terms. Since the reports are intended to be intelligible by the general public, this glossary of terms has been compiled to help provide some explanations for terms which may be used in the reports. This glossary is not meant to be exhaustive, but is rather meant to provide people with a well-rounded vocabulary and a basic knowledge of some of the terms and classifications used in the reports.

Definitions are not in any particular order.

Solar Flux:

The 10.7 cm (2800 MHz) radio flux is the amount of solar noise that is emitted by the Sun at 10.7 cm wavelengths. The solar flux is measured and reported at approximately 1700 UT daily by the Penticton Radio Observatory in British Columbia, Canada. Values are not corrected for variations resulting from the eccentric orbit of the Earth around the Sun. The solar flux is used as a basic indicator of solar activity. It can vary from values below 50 to values in excess of 300 (representing very low solar activity and high to very high solar activity respectively). Values in excess of 200 occur typical during the peak of the solar cycles. The solar flux is closely related to the amount of ionization taking place at F2 layer heights (heights sensitive to long-distance radio communication). High solar flux values generally provide good ionization for long-distance communications at higher than normal frequencies. Low solar flux values can restrict the band of frequencies which are usable for long distance communications. The solar flux is measured in "solar flux units" (s.f.u.). One s.f.u. is equivalent to 10^{-22} Wm^{-2} Hz^{-1}.

Sunspot Number:

This term is basically self-explanatory. It represents the number of observed sunspots and sunspot groups on the solar surface. It is computed according to the Wolf Sunspot Number formula: $R = k\,(10g + s)$, where 'g' is the number of sunspot groups (regions), s is the total number of individual spots in all the groups, and k is a scaling factor that corrects for seeing conditions at various observatories. Sunspot number varies in phase with the solar flux. Sunspot numbers can vary between zero (for sunspot minimum periods) to values in excess of 350 or 400 (in the very active "solar max" period of the sun's 11 year cycle). Solar flux is related to the sunspot number, since sunspots produce radio emissions at 10.7 cm wavelengths (as well as at other wavelengths). Two brands of sunspot numbers are widely used: SESC (Space Environment Services Center), at Boulder, CO and the International (formerly Zurich) provided by Observatoire Royal de Belgique in Brussels.

Running Average Sunspot Number:

Ionospheric critical frequencies are correlated with Wolf Sunspot Numbers **provided** suitable long-term averages are taken of both and seasonal effects are accounted for. The standard averaging technique for sunspots is the 12-month running average centered on the month in question. I doubt that the ionosphere is really influenced by future sunspot activity, it is more likely that other phenomena are responsible for both. The proper sunspot number to use in a propagation prediction program, is **not** the daily, **nor** the monthly, sunspot number, but **is** the 12-month running average International sunspot number, R_I.

X-Ray Background Flux:

This represents the average background x-ray flux as measured on the primary GOES satellite. This value basically represents the amount of x-ray radiation that is being received at the Earth by the Sun. Generally, active regions emit more x-ray radiation than non-active solar regions. Therefore, this value can be of use in determining the overall state of the solar hemisphere facing the Earth. This value is also useful for propagation prediction models; e.g., PROPHET, since ionospheric layer ionization is closely correlated with the background X-ray flux. This flux is stated using the same classification scheme for x-ray flares (given below).

Proton Fluence:

Although this term will seldom be referenced within the reports, it may be of use to make a note of it. Proton fluence is simply the total number proton particle fluxes measured by the GOES spacecraft at geosynchronous altitudes for protons of energies >1 Million electron Volts (MeV), >10 MeV and >100 MeV. The higher the proton fluence, the more intense proton bombardments are at geosynchronous altitudes. It can also be used implicitly to determine the approximate amount of ionization occurring in the upper atmosphere, as well as the proton penetration level into the atmosphere and possible satellite anomalies caused by the solar proton bombardments. Fluence for particles are given in the units: particles cm^{-2} $steradian^{-1}$ day^{-1}.

Tenflare:

A tenflare is associated with optical and x-ray flares. Solar flares emit radiation over a very wide range of frequencies. One of the more significant frequencies observed is the 10.7 cm wavelength band (2695 MHz). When a solar flare erupts, "noise" from the flare is received over this very wide range of frequencies. When the noise received on the 10.7 cm wavelength band surpasses 100% of the background noise level during a solar flare, a Tenflare is said to be in progress. The more intense solar flares are associated with tenflares. Almost all major flares are associated with tenflares. Generally, the greater the intensity of the burst of noise observed at the 10.7 cm wavelength band, the more significant the flare is said to be. The duration of the tenflare can also be used to determine the severity of the flare. Other important flare characteristics are also determined from the radio data observed from flares, which are closely related to the various physical processes which occur in flares. These characteristics are far beyond the scope of this document.

Electron Fluence:

Again, this term will seldom be referenced within the reports. It is analogous to "proton fluence" but is measured for electrons with energies >2 MeV. Fluence measurements are the same as those for proton fluence.

Magnetic A-Index:

The geomagnetic A-Index represents the severity of magnetic fluctuations occurring at local magnetic observatories. During magnetic storms, the A-index may reach levels as high as 100. During severe storms, the A-index may exceed 200. Great "rogue" storms may succeed in producing index values in excess of 300, although storms associated with indices this high are very rare indeed. The A-index varies from observatory to observatory, since magnetic fluctuations can be very local in nature. The A-index for Boulder Colorado (the same value reported on WWV and WWVH) will be the one referenced most often within the reports. Occasionally, the A-index for higher latitude stations may also be referenced for purposes of comparison. Magnetic fluctuations monitored locally here at Solar Terrestrial Dispatch will also be referenced, particularly during storm periods for descriptive purposes.

Magnetic K-Index:

The geomagnetic K-Index is related to the A-index. K-indices are scaled by comparing the H and D magnetometer traces (representing the horizontal and declination magnetic components) to assumed "quiet-day curves" for H and D. Each UT day is divided into 8 three-hour intervals, starting at 0000 UT. In each three-hour period, the maximum deviation from the quiet day curve is measured for both (H and D) traces, and the largest deviation (the most disturbed trace) is selected. It is then input into a quasi-logarithmic transfer function to yield the K-index for the period. The K-index ranges from 0 to 9 and is a dimensionless number. It is assigned to the end of the three hour period. The K-Index is useful in determining the state of the geomagnetic field, the quality of radio signal propagation and the condition of the ionosphere. Generally, K index values of 0 and 1 represent Quiet magnetic conditions and imply good radio signal propagation conditions. Values between 2 and 4 represent Unsettled to Active magnetic conditions and generally correspond to less-impressive radio propagation conditions. K-index values of 5 represent Minor Storm conditions and are usually associated with Fair to Poor propagation on many HF paths. K-index values of 6 generally represent Major Storm conditions and are almost always associated with Poor radio propagation conditions. K-index values of 7 represent Severe Storm conditions and are often accompanied by "radio blackout" conditions (particularly over higher latitudes). K-indices of 8 or 9 represent Very Severe Storm conditions and are rarely encountered (except during exceptional periods of solar activity). K-indices this high most often produce radio blackouts for periods lasting in excess of six to ten hours (depending upon the intensity of the event).

Sudden Storm Commencement or SSC:

An SSC is the magnetic signature of an interplanetary shockwave most often produced by solar flares. It is always a precursor to increased geomagnetic activity, most often followed within three to eight hours by a Minor to Major geomagnetic storm. It appears on the H (horizontal) trace of magnetometers. This phenomenon is detectable at almost all magnetic observatories world-wide within four minutes of each other.

Sudden Impulse or SI:

A sudden magnetic impulse is similar to an SSC. It represents a rapid momentary fluctuation of the geomagnetic field over a period of only a few minutes. It is generally associated with interplanetary shockwaves produced by energetic solar events and can (but need not always) be followed by increased geomagnetic activity.

Satellite Proton Event:

Proton events are almost always associated with energetic solar activity such as major flares. They are periods of increased proton bombardments at satellite altitudes. They can affect satellite transmission/reception if intense enough and can cause other satellite anomalies. Proton events may affect the ability of a HAM operator to establish contact with a satellite, and may affect the quality of television signals received by satellite (ie. cable tv may be affected). Satellite proton events occur within a few hours of a major proton flare. They are also often followed by a PCA event (see below).

Polar Cap Absorption Event or PCA:

A PCA is almost always produced by an intense solar proton flare. PCAs are the result of copious quantities of high-energy solar protons penetrating the Earth's atmosphere to levels of the order of 50 km, producing intense ionospheric ionization. The result is a complete (or near-complete) radio blackout over polar latitudes. A typical PCA lasts from 1 to 5 days and can severely effect the propagation of radio signals near or through polar regions. In intense, long-lasting events, direct entry of the high-energy solar protons to the upper atmosphere can extend equatorward as far as about 50° geomagnetic latitude. They occur almost coincident with satellite-level proton events, maximize in intensity within a few hours and then begin a slow decay that can last up to 10 days for intense events. A PCA is often followed within 48 hours by a SSC and a subsequent Minor to Major geomagnetic storm about 3 to 8 hours later.

Sunspot Classifications:

Sunspots are classified according to size, shape and spot density. They are classified using a set of three coded letters (Zpc) as follows:

Z - Modified Zurich class, labeled A through F plus H.
- A - Single small spot (single magnetic polarity).
- B - Very small distribution of small spots.
- C - Two or more small spots, at least one of which has a detectable penumbra.
- D - Moderately sized group of spots, several of which may have noticeable penumbrae. Magnetic complexity of D-type regions are usually capable of producing C and low-intensity M-class flares.
- E - Moderate to large area of a fairly complex system of sunspots, several of which have noticeable penumbrae and good definition. Often capable of producing minor C-class as well as major M-class flares.
- F - Large to very large area of a complex system of sunspots. These regions are often capable of producing major X-class flares as well as numerous major M-class and many C-class events (depending on their magnetic complexity).
- H - Single large to very large sunspot (not usually capable of producing significant energetic events). This type of sunspot is usually manifest in the dying phase of a sunspot group.
  - p - Penumbra type of the largest spot in the group.
    - x - Single spot.
    - r - Rudimentary.
    - s - Small symmetric.
    - a - Small asymmetric.
    - h - Large symmetric.
    - k - Large asymmetric.
  - c - Relative sunspot distribution or compactness of the group.
    - x - Single spot.
    - o - Open group (separated by quite a wide space).
    - i - Intermediate (moderate sunspot compactness in the group). c - Compact (very dense and complex spots within the group).

Example: A sunspot group classified as type DKO would be of moderate overall size (that is, the region encompassing all of the sunspots within the group would be of moderate size), the penumbra of the largest spot within the group would be large and asymmetric in shape, and the group would be "open" indicating that the sunspots within the region are not notably close together.

Magnetic Class:

The magnetic class of sunspots is important in determining how potentially volatile particular active regions may be. Sunspots are regularly observed using instruments capable of determining the magnetic polarity of sunspots and active regions. By also applying laws which have been formulated over the years, visual observations can also be used to establish the magnetic polarity and complexity of spot groups. There are basically 7 magnetic types of sunspots that are classified. They are described as follows:

Type A - Alpha (single polarity spot).
- B - Beta (bipolar spot configuration).
- G - Gamma (atypical mixture of polarities).
- BG - Beta-Gamma (mixture of polarities in a dominantly bipolar configuration).
- D - Delta (opposite polarity umbrae within single penumbra).
- BD - Beta with a Delta configuration.
- BGD - Beta-Gamma with a Delta configuration.

Example: A region labeled as having a magnetic classification of BG indicates that the sunspot region contains a mixture of magnetic polarities, but the dominant polarity of the group is bipolar.

Potentially very powerful and potent regions are those which have classifications of BG, BD and BGD. As magnetic complexity increases, the ability of an active region to spawn major energetic events likewise increases.

Solar Activity Description:

Solar activity is described (also applicable on WWV and WWVH) according to the number of flares which occur during the day. Activity is basically classified as follows:
- Very Low : X-ray events less than class C.
- Low : C-class x-ray events.
- Moderate : Isolated (one to 4) M-class x-ray events.
- High : Several (5 or more) M-class x-ray events or isolated (1 to 4) M5 or greater x-ray events.
- Very High : Several M5 or greater x-ray events.

Flare Classifications:

Flares are classified using one of two different systems. The first classification ranks the event by measuring its peak x-ray intensity in the 1-8 angstrom band as measured by the GOES satellites. This x-ray classification offers at least two distinct advantages compared with the second system of classification (optical): it gives a better measure of the geophysical significance of the event and it provides an objective means of classifying geophysically significant activity regardless of its location on the solar disk or near the solar limb. The classification scheme is as follows:

Class	Peak Flux (1-8 Angstroms in Wm^{-2})
A	$< 10^{-7}$
B	$< 10^{-6}$ but > class A
C	$< 10^{-5}$ but > class B
M	$< 10^{-4}$ but > class C
X	$> 10^{-4}$

The letter designates the order of magnitude of the peak value. Following the letter the measured peak value is given. For descriptive purposes, a number from 1.0 to 9.9 is appended to the letter designation. The number acts as a multiplier. For example, a C3.2 event indicates an x-ray burst with a peak flux of 3.2×10^{-6} Wm^{-2}. Since x-ray bursts are observed as a full-sun value, bursts below the x-ray background level are not discernible. The background drops to class A level during solar minimum; only bursts that exceed B1.0 are classified as x-ray events. During solar maximum, the background is often at the class M level, and therefore class A, B and C x-ray bursts cannot be seen. Bursts greater than 1.2×10^{-3} Wm^{-2}

may saturate the GOES detectors. If saturation occurs, the estimated peak flux values are reported.

The second system of classification involves a purely optical method of observation. A flare event is observed optically (in H-alpha light) and is both measured for size and brightness. This classification therefore includes two items of information: a descriptor defining the size of the flare and a descriptor defining the peak brightness of the flare. They are listed below:

Importance	
S	- Subflare area ≤ 2.0 square degrees.
1	- 2.1 ≤ area ≤ 5.1 square degrees.
2	- 5.2 ≤ area ≤ 12.4 square degrees.
3	- 12.5 ≤ area ≤ 24.7 square degrees.
4	- area ≥ 24.8 square degrees.

Brightness	
F	- Faint.
N	- Normal.
B	- Brilliant.

Example: A major flare rated as a class M7.4/2B event indicates that the flare attained a maximum x-ray intensity of 7.4×10^{-5} Wm^{-2}. The "2B" portion of this specification indicates that the flare was an importance 2 flare (≥ 5.2 and ≤ 12.4 square degrees) and was optically Brilliant. This sample flare is a powerful event. Flares that reach x-ray levels in excess of class M4 can begin to have an impact on the Earth. Likewise, flares rated 2B or greater are generally capable of influencing the Earth, particularly if accompanied by Type II and IV radio sweeps (discussed below).

Sweep Frequency Events (Type II, III, IV and V):

Energetic solar events often produce characteristic radio "bursts". These bursts are generated by solar material plunging through the solar corona. Type III and type V events are caused by particles being ejected from the solar environment at near relativistic speeds. Type II and IV events are caused by slower-moving solar material propagating outward at speeds varying between approximately 800 and 1600 kilometers per second. Type II and IV radio bursts are of particular importance. These sweep frequency radio events are signatures of potentially dense solar material which has been ejected from the solar surface. If the region responsible for these events is well positioned, the expelled solar material may succeed in impacting with the Earth. Such an impact often causes an SSC followed by Minor to Major geomagnetic storm conditions and significantly degraded radio propagation conditions. It is therefore interesting to pay attention to events which cause Type II and/or IV radio sweep events, since they may indicate the potential for increased magnetic activity (and decreased propagation quality) within 48 hours. It should be noted, however, that predicting degraded terrestrial conditions is significantly more complex than simply observing whether the energetic event had an associated Type II or IV radio sweep. Flare position, proton spectra, flare size, event duration, event intensity and a host of other variables must be analyzed before a qualitative judgment can be made.

It should also be noted that sweep frequency radio events are capable of producing Short Wave Fades (SWFs) and Sudden Ionospheric Disturbances (SIDs). Depending on the severity of the event, the duration of SWFs and SIDs may last in excess of several hours with typical values being approximately 30 minutes. SWFs and SIDs cause absorption of radio signals (due to intense ionization) at frequencies up to and well in excess of 500 MHz. Microwave continuum bursts can affect frequencies up to 30 GHz. Frequencies in the HF region can be completely blacked out for a period of time during intense energetic events.

Classifications of Auroral Activity in the Reports:

Auroral activity is rated as either not visible, low, moderate, high, very high or extremely high. These classifications are defined according to the brightness achieved by auroral activity, visual activity (ie. changes of form or structure), whether the aurora is pulsating, and according to the intensity and fluctuations of color in the aurora. The various levels of activity are defined below:

- Not visible: Self-explanatory.

- Low: Low intensity aurorae consisting mostly of diffuse, dim, and lifeless activity. Generally no rapid changes in form or structure are discerned with auroral activity that is classified as "low."

- Moderate: Moderate intensity auroral activity which consists of diffuse aurorae intermixed with curtain aurorae or other forms of relatively-low activity aurorae. Moderate activity may include beams or rays of aurorae which travel either east or west with time. No color fluctuations or significant brightenings of aurorae are associated with moderate intensities.

- High: High intensity auroral activity is activity associated with very bright, active displays that may exhibit changes of color and rapid pulsations. High activity is generally confined to curtain aurorae and moderate-intensity pulsating aurorae.

- Very High: Very high intensity auroral activity is usually only experienced over the high latitude regions where zenith aurorae and significant auroral displays occur. Activity classified as very high consists of most auroral forms of activity, but the activity is always very bright and extremely active. Curtain aurorae may change form and color rapidly. Zenith aurorae may become exceedingly bright and colorful.

- Extremely High: Extremely high auroral activity is only rarely encountered. Activity at this level of intensity is most often experienced within the middle and/or low latitude zones during significant periods of geomagnetic activity. The expansion of the auroral zone equatorward and poleward produces the intense activity over regions equatorward of the normal position of the auroral oval. This activity usually consists of exceedingly bright, rapidly fluctuating, strongly pulsating, color-varying auroral activity. Levels of auroral activity this high are usually only associated with "rogue flares", which may occur only once or twice during a solar cycle.

For a good discussion on the topic of solar flares and terrestrial impacts, consult the book *Solar Flares* by H.J. Smith and E.V.P. Smith (publisher: Macmillan, New York). Although this book is a few decades old (1963), it provides an excellent knowledge base to build upon and a wealth of information on flares in general.

I. Morphological Analysis of Phenomena Table of Contents

Abstract

This document is intended to aid those who are interested in interpreting and using the material presented in the various solar terrestrial reports that are posted over the networks. This document has been written under the assumption that the reader is unfamiliar with the terrestrial impacts of solar-related activity. It is therefore not intended for those who already have a knowledge of solar physics and/or geophysics. Some of the terms contained in this document are undefined. For definitions of undefined terms, refer to the Glossary of Solar Terrestrial Terms starting on page 1.

There are two parts to this document, split into two completely separate sections. This first part describes the morphology of solar and terrestrial phenomena. Part I is fairly extensive and is intended to give the reader enough background knowledge to understand, interpret and apply the information presented in part II. Part II discusses the format and proper interpretation of the solar terrestrial reports. They should be read in proper sequence in order to be best understood.

1. Introduction

In March of 1989, some spectacularly powerful solar terrestrial events occurred. An very complex and active solar region erupted with almost unprecedented levels of activity. Flare activity broke records that were held for over 30 years. Intensely severe geomagnetic storming induced electrical currents in power lines, which resulted in a total collapse of the Hydro Electric power distribution network in Quebec. This resulted in the loss of electrical power for over 6 million Canadians. Telecommunications equipment experienced powerful voltage surges on the power supply lines of transatlantic fiber-optic cables in excess of 700 volts. Oil pipelines experienced rapid strong variations in pipe-to-soil potentials, producing electrolytic corrosion at flaws in the pipeline coating. Radio propagation was severely effected by both strong PCA activity and severe geomagnetic storming. HF radio signals were completely blacked out over many global locations, and remained at very poor levels for at least 24 hours. Auroral activity was easily visible as far south as Florida (and even further). Some satellites, unable to withstand the rapid fluctuations in solar wind pressure, began tumbling out of control.

It is well known that solar activity has an astonishing influence on terrestrial Earth-based systems. The events of March 1989 will long be remembered as a prime example of the power and influence the Sun can have on our environment and activities.

The solar terrestrial reports and associated alerts/warnings have been posted over the networks in order to aid in the prediction of terrestrial conditions which might be expected from solar and other related activity. This document is intended to help explain the nature of these various reports so that application of the data contained therein can be properly applied to the various fields which can be affected.

Part I of this document will examine the basic physics behind such solar phenomena as sunspots, flares, and coronal holes in terms that should be easily understood by the layman. Following this, a basic overview of the geomagnetic field and some of its important features will be discussed. The characteristics of radio wave propagation will then be explored for VLF, HF and VHF signals as they relate to geomagnetic and auroral activity. Following this, the characteristics and behavior of auroral activity will be considered in conjunction with astronomical observations and magnetic fluctuations. Concluding this section will be a discussion on the impact of severe geomagnetic storms. This discussion will include the effects of strong magnetic storming on such environments as electrical power distribution networks, atmospheric circulation, and radio communications.

Part II of this document will delve into the format of the solar terrestrial reports. The proper interpretation of the predictions and various charts contained in the weekly Solar Terrestrial Forecast and Review will be discussed. An examination of the flare alerts and warnings will then be conducted, followed by an analysis of the geomagnetic and auroral storm alerts which are posted when necessary. Concluding this section will be a brief overview of the material covered in parts I and II of this document. Hopefully, this document will be cohesive and interesting enough to be of value to those who are serious about examining the relationships between solar activity and terrestrial impacts.

2. Characteristics of the Sun

The Sun is a dynamic, complex object that we are only now beginning to understand. It has been a source of study and wonderment for centuries. Although many questions have been raised regarding its influence on the Earth, aside from the fact that it is our primary source of energy, only during the past century have real achievements been made toward understanding its intricate nature and influence on our environment.

We now know, for example, that the Sun has regular, fairly constant cycles. Through persistent observations and meticulous record keeping, we know that the Sun runs through cycles of activity with periods of about 11 years. We know that the Sun also has a longer, 22 year cycle in which the magnetic polarity of the solar poles actually reverse sign. We know that the Sun is a rotating sphere that completes one revolution approximately once every 27-28 days. We also know that areas near the solar poles rotate at slower velocities and therefore take longer to complete one revolution than areas near the solar equator (this has been termed "differential rotation").

It has long been known that visibly dark regions often plague the surface of the Sun. The ancient Chinese noticed these dark spots at least 15 centuries ago. Early solar astronomers noticed, over time, that the number of spots observed on the Sun vary in cyclic patterns. They also noticed that the number of aurorae that were seen were positively correlated with the number of sunspots observed on the Sun.

It wasn't until the first satellites investigated the domain of space, that we began to realize the intricate nature and varying forms of activity that occur on the Sun. We discovered and studied what is called the solar corona, a great expanse of superheated rarefied gas extending outward many solar radii from the solar surface. We examined in great detail the morphology of solar flares, one of the most powerful natural explosions known to man. Our investigations have revealed a great abundance of radiations emitted by the sun, much of which is filtered out by our terrestrial atmosphere. We have developed new techniques of studying the Sun at different optical wavelengths, which has given us a wealth of new information regarding the physics of phenomena seen on the Sun. We have witnessed many forms of activity: prominences, filaments, plages, faculae, granules, and many other forms of activity.

The first step in understanding the relationships between solar activity and terrestrial phenomena is to obtain a knowledge of some of the basic characteristics of the Sun and its attendant activity. In this first section, we will attempt to cover enough material to explain some of the properties and relationships required for strong interactions between the Sun and the Earth.

2.1. Sunspots and the Solar Flux

Galileo is credited as being the first person to discover sunspots telescopically around the year 1610. He immediately noted the presence of black spots on the bright surface of the Sun. It was also observed that these spots moved across the surface of the Sun and gradually changed shapes from day to day. These spots puzzled solar astronomers for years and resulted in some interesting, although incorrect, theories regarding their origin.

Through time, we have developed better instruments to resolve the features of sunspots. This has increased our factual knowledge of sunspots which has allowed us to refine our theories to model sunspots more accurately.

We now know that sunspots are cool regions of the Sun. They are regions approximately 2,000°K cooler than the surrounding surface of the Sun. The sun's surface (called the photosphere), is about 5,800°K. (The absolute, or Kelvin, degree is the same as the centigrade degree, but the zero of the absolute temperature scale is 273° below 0°C). The cooler temperatures within sunspots are what cause them to appear darker than the surrounding photosphere. In actuality, a sunspot separated from the Sun and placed in the blackness of space would radiate a great deal of energy, and would appear as an intense source of bright white light. It is only due to the contrasting temperature of the sun's surface that cause sunspots to appear dark.

The dark central portion of a sunspot is called the umbra and is most often associated with a less dark region called the penumbra. Sunspots vary greatly in size and complexity, but are generally around 37,000 kilometers in diameter. Sunspots almost always form in groups of two or more.

Sunspots are regions of intense magnetic fields. The magnetic fields originate from deep within the Sun and gradually propagate outward. When they reach the surface, they cause the gases within the intense core of the magnetic field to cool. Magnetic fields forming a sunspot often curve around and re-enter the Sun at another nearby location. At each point where the magnetic field enters or exits the sun, a sunspot is formed.

Sunspots rotate in the same direction as the sun, and at the same (or nearly the same) speed as the surrounding gases. Sunspots near the solar poles therefore take longer to complete one revolution than do spots near the solar equator. Sunspots generally take about 27 days to complete one revolution near the solar equator. This increases to over 35 days for sunspots existing at high solar latitudes.

Sunspots have distinct life cycles. Although the lifetime of a single spot can extend for many weeks (sometimes months), the activity cycle of sunspots is very distinct. Sunspots begin as small specks (called "pores") which often grow rapidly into larger more distinct spots. As they grow in size, they develop penumbral regions surrounding the dark umbral core. Nearby, other sunspots often form and grow simultaneously. Unlike the cooler temperatures within the spots themselves, the outer regions of the spots (outside of the penumbral zones) are often superheated and appear brighter than the rest of the photosphere. These brighter regions, called faculae mark the presence of strong magnetic fields near the surface of the Sun. These are all characteristics of a maturing sunspot group.

As a sunspot group ages, the spots within the group begin to spread apart and drift away from what was once a compact cluster of spots. This spreading is caused by the drift of the associated magnetic fields away from the central spawning region. As the magnetic fields drift, they often decrease in intensity and diffuse into weaker regions. Sunspots begin to fade away and disappear. Eventually, all of the sunspots fade away and die, leaving only a brighter patch of faculae marking the region that once was an active sunspot forming region. Over time, even the faculae disappear, leaving no trace that sunspots once existed over that region.

This life cycle is apparent in many sunspot groups that forms. However, not all sunspot groups behave this way. Some groups of sunspots never reach full maturity before perishing. Others may sustain mature configurations for weeks before beginning to show signs of decay. And still others may exhibit multiple cycles of growth and decay before finally dying. Although the morphology of sunspots varies dramatically, the general life cycle above applies in most cases.

Sunspots are sources of enhanced radiation emissions. For the person dependent on long-distance radio communications, sunspots can help provide the enhanced radiation necessary to provide excellent radio conditions over long-distance signal paths.

The radiation emitted by sunspots are most often concentrated within groups of sunspots lying in relatively close proximity to each other. The radiation covers a host of different wavelengths from Gamma rays all the way down to radio-waves. The radiation emitted by all of the sunspot groups visible on the Sun are measured by a variety of instruments. Satellites constantly monitor the radiation levels from the Sun which cannot be measured from the ground (due to the filtering effect of the Earth's atmosphere). Radiation which does reach ground levels are measured by sensitive radio receivers tuned to those wavelengths.

One of the wavelengths of radiation which does penetrate the Earth's atmosphere down to ground-levels is the 2800 MHz band (or the 10.7 centimeter wavelength band). This intensity of noise (i.e.,. the intensity of the radiation) emitted from the Sun on this wavelength is measured daily by the Algonquin Radio Observatory in Ottawa Canada. The intensity measurements obtained from this observatory are broadcast world-wide by radio station WWV (and all other related stations) in the form of a solar flux. This solar flux represents the intensity of the solar radiation being measured at the Earth's surface from the Sun.

The solar flux is fairly critical in radio communications work. It has been found that the radiation intensity at 2800 MHz correlates fairly well with the ionization levels at altitudes sensitive to high frequency (HF) radio communications. High solar flux values generally translate into better radio communications. It also generally marks a period of better long-distance communications using higher frequencies. The maximum usable frequency (MUF) during periods of high solar flux often exceed 50 MHz, providing long-range communications capabilities for operators using very high frequencies (VHF).

The solar flux (and hence, the radiation intensity from the Sun at 2800 MHz) is very dependent on the number of sunspots. Large sunspot groups can produce steep increases in the solar flux. Solar flux values in excess of 300 are indicative of extensive sunspot activity and may coincide with very good long-range communications on HF and perhaps even lower VHF frequencies. Low solar flux values below 100 are usually indicative of periods where very little sunspot activity is visible on the Sun. The solar flux is therefore an excellent means for monitoring sunspot activity. Increases in solar flux indicate the emergence or growth of sunspot areas on the sun, while decreases in the solar flux indicate the disappearance or death of sunspots on the Sun.

Since the Sun rotates with a period averaging approximately 27-28 days, it is reasonable to question whether or not the number of sunspots visible on the Sun fluctuate with a period of around 27-28 days. This is in fact, true. The rotation of the Sun often causes sunspots to rotate out of view and then reappear on the opposite side of the Sun about 14 days later. We say 14 days later because by the time a sunspot group has rotated out of view, it has already completed half of its rotation period. So it only takes 14 days for a sunspot group to rotate to the opposite side of the Sun and back into view.

This cyclic behavior is also manifest in the solar flux. Because the solar flux is dependent on sunspot activity, the value of the solar flux often fluctuates in tandem with sunspot activity. As a sunspot group rotates out of view, the solar flux decreases in value (sometimes dramatically if the sunspot group is extensive). Approximately 14 days later, the same sunspot group may (assuming it doesn't die) rotate back into view on the opposite side of the sun, with an attendant increase in the solar flux.

This cyclic pattern can be easily seen when the solar flux is plotted over time. The Solar Terrestrial Forecast and Review plots the solar flux graphically over a period of 60 days. By observing the cyclic pattern, it is relatively easy to determine approximately when the next peak will occur. Using this information, enhanced general radio conditions can also be predicted with relatively good accuracy. As will be seen in later sections, however, the quality of radio conditions depends on much more than simply the solar flux.

2.2. The Sunspot Cycle

Just as the number of sunspots fluctuate with periods of near 27-28 days, the Sun exhibits a longer period cycle which directly effects the population of sunspots that form over the entire surface of the Sun. This cycle has been called the sunspot cycle since the primary effect of the cycle is on sunspot activity.

To discern this longer cycle, it is necessary to plot the number of sunspots observed on the surface of the Sun persistently for a period of about 11 years. If this is done, it becomes apparent that the number of sunspots which form and become visible decrease to a minimum over a period of about 6 to 8 years, followed by a fairly rapid increase to a peak over a period of about 3 to 5 years. This cyclic behavior represents the sunspot cycle.

The solar flux likewise follows an 11 year cycle. But since the solar flux represents (at least in part) the quality of radio communications (i.e.,. distance and stability of communications), radio communications also follow a cyclic pattern that is in phase with the sunspot cycle.

There are many other aspects of solar activity which closely follow the sunspot cycle. These other forms of activity will be covered in later sections.

2.3. The 22 Year Solar Cycle

Superimposed on the 11 year solar cycle is yet another cycle with a period of about 22 years. This cycle is primarily magnetic in nature and can be seen only by observing the polarity of the solar poles.

The Sun has an extensive magnetic field which reaches far out into interplanetary space. If a compass were held while standing on the sun, the compass needle would deflect and point towards the north and south solar poles just as it does for us here on Earth. However, unlike the Earth, the sun's magnetic poles reverse polarity approximately once every 11 years for a total period of 22 years. That is, once every 11 years, a person standing on the Sun with a compass would notice the needle reversing directions. Another 11 years later, the direction of the compass needle would reverse directions again, pointing back in the same direction as it originally did when first observed. The characteristics of this cycle were first noted by Hale[1] and Hale and Nicholson[2]. It is a fairly important cycle as will be explained below.

As was seen in section 2.1, sunspots are intimately linked to magnetic fields. This 22 year cycle affects the polarity of the sunspots that are formed in the northern and southern solar hemispheres. It also affects the polarity of the interplanetary magnetic field which is detected and measured from space by spacecraft.

Near the minimum of each solar cycle, the polarity of the solar magnetic poles reverse sign. This does not occur suddenly. It can be a rather slow process. Often, the solar poles become the same polarity before the full reversal process completes. When the northern solar hemisphere has a northern-magnetic pole, sunspots which form in that hemisphere have opposite magnetic characteristics to sunspots which are formed in the southern hemisphere. After the poles reverse magnetic polarity, the sunspots which form in the northern hemisphere likewise reverse magnetic characteristics.

This cycle is important because it affects almost all of the magnetic characteristics of the Sun as a whole and requires changes in the way we examine sunspot groups and their behavior.

2.4. The Solar Atmosphere

The sun's atmosphere can be divided into three distinct regions, or layers of differing physical properties. Each of these layers are very important to those who expect to understand the phenomena which occur within the various regions. We will very briefly review the properties and characteristics of these three regions, and will note the types of phenomena which occur in the various layers of the solar atmosphere.

2.4.1. The Photosphere

The solar photosphere is the lowest layer of the solar atmosphere. This layer resides between 200 km and 400 km deep. The photosphere is responsible for contributing most of the light that we receive here at the Earth. It is the photosphere which produces the so called limb darkening effect, where the radiation intensity emitted from the Sun decreases from the center of the solar disk to the edge (or limb) of the Sun. As we look closer to the limbs, our line of sight approaches tangency to the solar sphere and therefore travels through a greater volume of the upper photospheric layers. Because light from the deeper layers cannot reach us from the limbs due to the thickness and absorbing characteristics of the photosphere, we do not see as deeply into the photosphere when we look at the limbs, hence the limbs appear darker than does the central solar disk.

As one would expect, the temperature of the solar photosphere increases with increasing depth. In general, the effective solar photospheric temperature is calculated (using Stefan's law) to be about 5780°K. The photosphere represents the coolest region of the Sun. The temperature increases as you look deeper into the photosphere, and it also increases as you travel outward away from the photosphere.

The average density of the photosphere is relatively small; even smaller than the density of the Earth's atmosphere. In fact, the average density of the photosphere is only about one thousandth that of the Earth's atmosphere, yet we can only see to a very small depth in the photosphere due to the high absorption and continuous spectrum of radiation which is emitted by the photosphere.

The photosphere is not a particularly smooth surface. Through observations using powerful telescopes, plumes of rising and falling gas in the photosphere have been found. These granules can be seen over the entire surface of the photosphere and range in size from about 200 km to over 1800 km. Their average size is about 700 km. They are not a long-lived phenomena. Average lifetimes for granules are only about 8 to 9 minutes.

Sunspots as seen with the naked eye, are viewed as they appear on the photospheric layers of the Sun. Their domain, however, is not restricted to the photosphere. Indeed, they can have profound effects in the sun's chromosphere as well (discussed below).

2.4.2. The Chromosphere and Spicules

Immediately above the photosphere lies the chromosphere, an area of the sun's atmosphere where solar flares originate. The chromosphere is much thicker than the photosphere. It resides between the upper surface of the photosphere and extends to about 12,000 km above the surface of the photosphere. There are basically three regions of the chromosphere which are defined according to the temperature stratification which occurs in that region. The lower layer of the chromosphere extends to an altitude of about 1000 km. The middle layer extends from 1000 km to about 4000 km, while the upper chromosphere extends from 4000 km to about 12,000 km. Temperatures increase rapidly from the lower chromosphere to the upper chromosphere. At the upper edge of the chromosphere, the temperature can increase to values in excess of 100,000°K.

The chromosphere is the home of another type of phenomena, called the spicule. Spicules, when viewed at the solar limb using an appropriate monochromatic filter (such as an H-alpha filter), appear as grass-like protuberances that project against the black background of space. They occur primarily in the upper middle and upper layers of the chromosphere.

2.4.3. The Corona and Coronal Holes

The highest and most diffuse region of the solar atmosphere is known as the corona. This is a region of very low density gases that are superheated to exceedingly high temperatures. It can only be seen during a total solar eclipse, or by using a special instrument called a coronograph which automatically occults the bright solar disk, in effect, simulating a total solar eclipse.

The solar corona can only be seen when the bright surface of the Sun is completely blocked out. The low density of the corona inhibits its ability to give off light, hence its surface brightness is only a few millionths that of the sun's disk.

The corona has no well-defined upper boundary. When viewed using a coronograph or during a total solar eclipse, the corona can be discerned to distances in excess of several solar radii. Indeed, it extends to great distances in space, out to a distance of several million kilometers, where it gradually becomes the solar wind.

Whereas the temperature of the photosphere is only about 5800 K, the temperature in the solar corona soars to values in the range of 1 to 2 million °K. Pressure waves propagating outward from the sun's convective zone in lower levels provide the energy that heats the sun's tenuous coronal regions to such extraordinarily high temperatures.

The solar corona exhibits several forms of activity. When viewed using a coronograph, bright transient features become visible. These bubble-like projections called solar transients or coronal mass ejections (CMEs) are relatively short-lived and expand rapidly outward through the corona. These disturbances are associated with radio bursts that are observed here on Earth.

The high temperatures in the solar corona are sufficient to produce copious amounts of x-ray radiation. This wasn't discovered until the early 1970s when the Skylab mission revealed the intricate nature of the solar corona. When viewed at x-ray wavelengths from space, the inner solar corona appears blotchy, with many bright points and extensive areas where very little x-ray radiation appears to be emitted. These areas devoid of x-ray emissions, are called coronal holes. It has been found that the passage of these coronal holes through the central solar meridian are almost always followed within 3 to 5 days by increased geomagnetic activity here on Earth. It is now known that these coronal holes are regions where the magnetic field lines from the Sun are open (i.e.,. they don't immediately curl around back to the sun, but instead escape into interplanetary space). Since the charged particles in the Sun naturally follow the magnetic field lines, the charged particles are allowed to escape into interplanetary space when the magnetic field lines of the Sun are open. For this reason, coronal holes are often locations where escaping high-speed streams of charged particles from the Sun are allowed to impinge on the Earth's space-environment, causing increased geomagnetic activity and occasional magnetic storms.

Coronal holes most often reside near the solar poles, where the magnetic field lines extend radially out into interplanetary space. It is believed that the density of charged particles and also the speed of the solar wind are increased over these regions. The Ulysses space mission will hopefully confirm these theories. The Ulysses spacecraft is on its way to Jupiter, where it will use the massive gravitational pull of the planet to slingshot the spacecraft at high velocities in an orbit that will carry it over the solar poles to measure many aspects of the environment there. The solar poles have never been seen before in any great detail. Moreover, we are not able to determine the characteristics of space over the solar poles, since the orbit of the Earth never carries us beyond solar latitudes in excess of about seven degrees on either side of the solar equator. Hence, there is a significant amount of interest among solar physicists with regards to this mission.

Near the solar poles, coronal holes do not affect the Earth. Their primary effects propagate well to the north and south of the Earth's orbital plane. Not until the coronal holes migrate toward the solar equator do we begin to notice the effects of coronal holes. When coronal holes migrate to solar latitudes below approximately 30° to 40°, the relatively high speed streams of charged particles which emanate from these regions are able to begin to impact on our terrestrial environment.

Coronal holes rotate with the Sun. They are therefore capable of producing recurrent activity each time they rotate around the Sun. As they rotate, they change their form. Sometimes they expand in size. Sometimes they contract and disappear. During periods of sunspot maximum, their forms change rapidly and their recurrent effects diminish. The numerous active regions which plague the surface of the Sun during sunspot maximum are blamed for the rapid changes in form, appearance and death of coronal holes. Coronal holes formed during the sunspot minimum, however, are often long-lived and may last for many solar rotations before they finally fade away or migrate back toward the solar poles. During these periods, recurrent geomagnetic activity becomes well established.

2.5. Forms of Solar Activity

Among the various forms of solar activity are plages, faculae, prominences, filaments and the powerful explosions known as solar flares. All of these forms of solar activity are associated with active regions (sunspots). However, their manifestations and triggering mechanisms vary considerably.

In the next several sections, we will briefly examine some of the properties of these phenomena, concentrating most heavily on the aspects of solar flares, erupting prominences and disappearing filaments, which have the most profound effects on the Earth.

2.5.1. Plages and Faculae

The terms plage and facula are often used synonymously. In fact, Deslandres originally introduced the words with the phrase *plage faculaire*. Since then, the terms have evolved into two similar, yet separate phenomena. The term faculae is now used to denote the bright regions seen in white light surrounding sunspots (as is noticed when sunspots are viewed near the solar limbs). Faculae are therefore, photospheric phenomena. Plages, on the other hand are chromospheric phenomena and can only be observed when viewed through an appropriate monochromatic light filter (such as an H-alpha filter).

Plages and faculae are not separate phenomena. Rather, they are the same phenomena manifested at different altitudes in the solar atmosphere. Faculae may therefore be considered to extend into the chromosphere, where the same phenomena is witnessed as chromospheric plage.

As a general rule, the plage outlives its associated facula, often by several weeks. Both types of activity form around active regions and can extend to quite large distances around the active region. Plage and faculae do not extend as far north and south as they do east and west. Their east-west extensions cause their apparent shapes to become elongated. They typically follow in the steps of the active regions and are always the last optical phenomena to disappear when an active region dies. (The magnetic fields associated with the active regions are ultimately the last detectable remnants to fade away. The magnetic fields therefore, outlive plages and facula.)

Faculae contain bright granules which combine to form coarse mottles having diameters of about 5,000 km. These mottles tend to string together into chains. These chains of mottles are what compose the faculae. The temperature in the upper photosphere where the faculae form is higher than the surrounding photosphere. Also, the temperatures in deeper layers of the photosphere over the faculae tend to be lower than the upper photospheric layers. For these reasons, faculae do not exhibit limb-darkening when viewed near the solar limbs. They also disappear from view when seen away from the solar limbs under white light, for the same reasons.

The associated chromospheric plage can be viewed against the solar disk or near the solar limbs when seen through an appropriate monochromatic filter. By observing the chromospheric plage through appropriate filters, we have been able to determine the characteristics of plage associated with active regions. For example, it is known that plage and/or faculae which form away from active regions do not live as long nor do they attain the sizes and intensities found in the regions surrounding active sunspot groups.

2.5.2. Prominences and Filaments

Prominences are structures seen protruding from the relatively cool chromosphere into the hot corona. They typically extend to heights of 30,000 or 40,000 km above the chromosphere, but can attain heights as high as 100,000 km in some cases. Prominences are only seen near the solar limbs.

When prominences are viewed against the solar disk, the name changes to a filament. As prominences rotate into view such that they are seen against the solar disk, they appear as long stringy dark filaments that can stretch for distances up to 200,000 km. Although long in appearance, their widths are usually relatively small, near about 6000 km. Prominences and filaments vary considerably in dimensions. They can be very small, the size of chromospheric spicules, or very large as was mentioned above.

Prominences form both near active regions and away from active regions over apparently quiet areas of the solar surface. Prominences which originate away from centers of activity are generally known as quiescent prominences, and are usually less active and live longer than prominences which form near active regions. Active prominences are those which form near active regions. The fluctuating energy output and unstable environment cause active prominences to display some impressive forms of activity. Active prominences are, as a rule, associated with sunspots and occur in the earlier part of the life of a center of activity. This does not mean that quiescent prominences cannot undergo sudden changes. For example, sometimes a quiescent prominence starts to rise slowly, but rises faster in the middle than at the ends, thus

developing into an arch. As the arch expands at an increasingly higher velocity, attaining several hundred km/sec, the material disperses and fades to invisibility. Such eruptive prominences have been known to reach heights of 1.5 million kilometers above the solar limb. When seen on the disk as filaments, eruptive prominences are represented by the sudden disappearance of the filament (or a disappearing filament). Disappearing filaments (and thus, eruptive prominences) can release huge quantities of energy which can produce terrestrial impacts here on the Earth.

Erupting prominences and disappearing filaments are one and the same, only viewed at different positions on the solar disk. The majority of eruptions or disappearances are only temporary. Usually, the original prominence reforms over the same region and in nearly the same configuration within a few days.

There are many different types of prominences associated with varying levels of solar activity. Prominences of greatest interest to us are surge-type and loop-type prominences, which are manifestations of unusually energetic solar activity. Flares often produce surge and loop type prominences.

The typical surge-type prominence is a confined jet of material rising out of the chromosphere with a velocity of several hundred km/sec to a height of some tens of thousands of kilometers. After reaching a maximum height, the material usually falls back to the surface along nearly the same path as the outgoing matter. Like most prominences, surges show fine structures in the form of threads of luminous matter. Several surges can occur in the same region and using the same trajectories as other surges. The lifetimes of most surges are short, usually lasting only a few minutes, although they have been known to endure for several hours.

Loop-type prominences are likewise, associated with considerable amounts of flare and coronal activity. The prominence loops often form from bright knots or arcs at considerable heights above the limb, perhaps 100,000 km. Material streams down along two main curved arteries, and soon the prominence takes on a true loop shape, with the two arms meeting in a single point near, if not in, a sunspot. Loops usually last a few hours or less. At the end of their lives, they fade and disintegrate. Quite often, the last visible features are the high, now fainter, knots from which they originated. Loop prominences exhibit a peculiar spectral line called the coronal yellow line. This spectral type (made from Ca XV) indicates that the temperature of the medium surrounding the loop is high. Moreover, the spectra of the loop prominences themselves point to temperatures as high as almost any found among prominences and bear a close resemblance to flare spectra.

Although there are similarities in activity between quiescent and active prominences, active prominences are always more energetic and have higher temperatures. Quiescent prominences have kinetic temperatures of around 6,000 to 15,000°K, while active prominences may have temperatures that exceed 25,000 to 50,000°K. Loop and surge type prominences most often exhibit these higher temperatures.

The average lifetime of a filament is about 25 days. Compare this with the lifetime of a quiescent prominence, which can last up to eight or nine solar rotations. Quiescent prominences are therefore, considerably more stable unless an active region forms near a quiescent prominence.

Filaments tend to migrate toward the nearest heliographic pole. They form near the sunspot-forming zones and proceed to travel toward the poles. As they travel, shorter filaments often combine with longer filaments to form a very long filament chain. Many filaments do not manage to make it to the solar poles. Indeed, active regions can completely annihilate filaments which wander into their domain. Filaments can also simply disintegrate over time. However, the general tendency is for poleward movement of the filaments.

The high latitude filament zone becomes most prominent during the sunspot minimum years. During these years, the polar filament zone, known as the polar crown, continues to move poleward during the new solar cycle. Polar filaments are characteristically more stable than filaments near the sunspot forming zone (nearer to the solar equator ranging from about 30° latitude during sunspot minimum to about 5° in latitude during sunspot max.

2.5.3. Solar Flares

One of the most powerful natural explosions known to man is the solar flare. This relatively short-lived explosion occurs over complex sunspot groups. They can be immensely powerful. A large solar flare can release energy equivalent to a 10 billion megaton bomb.

Solar flares can be devastating to our terrestrial environment. Among some of the effects which are experienced in and around the Earth are bombardments of huge doses of ultraviolet radiation, which have been linked to global reductions in the ozone concentrations which protect us from hard ultraviolet radiation. Flares can send out vast quantities of highly energetic protons which can penetrate our Earth's atmosphere to tropospheric heights. Some powerful flares have been well correlated with anomalies in atmospheric circulation, affecting our weather and climate for relatively short periods of time. Flares have completely knocked out radio communications over long distances and have caused significant disruptions in ground-to-satellite and satellite-to-ground communications. The massive interplanetary shockwaves which can propagate outward from powerful solar flares can create exceedingly intense geomagnetic storms which can cause a multitude of problems, such as a lack of compass accuracy, loss of radio communications, and heavy currents induced into long conductive elements such as pipelines, railway tracks, telecommunications cables, and electrical power transmission lines. Strong geomagnetic storms have caused electrical power transformers to explode, large-scale blackouts for millions of people, and a great many electrical brownouts and surges. The shockwaves from solar flares (sudden changes in the velocity, density and pressure of the solar wind) have caused satellites to begin tumbling out of control. The highly charged particles which engulf the environment of satellites have also damaged the electronic components in some satellites. Indeed, solar flares can have a profound influence on our terrestrial environment.

Solar flares may be defined as a sudden release of energy causing a sudden brightening of the chromosphere. It is important to note that flares do not occur at the surface of the photosphere (the area that we discern as the surface with our eyes). Flares are chromospheric phenomena, and as such, occur above the photospheric regions.

The energy released by solar flares comes from magnetic energy which has been stored and accumulated over time in an active region. Generally, solar flares require strong magnetic gradients. This is particularly true for the more powerful class of flares known as proton flares.

The process whereby flares occur is basically as follows. An active region forms and develops. As it develops, the magnetic fields associated with the sunspot group intensify. Gradients between opposite poles of the magnetic fields associated with the active region increase. This process may be represented by an elastic that is stretched over time to near the breaking point. At some point, the elastic suddenly snaps, releasing all of its stored energy in a very short time. The sudden release of energy that was pent up in the magnetic fields causes a sudden and intensive explosion which superheats the chromosphere and nearby regions to temperatures of near 5 million °K. Particles are often explosively ejected from the Sun at this time, being accelerated to near relativistic speeds within fractions of a second. These types of flares are known as proton flares and can have a strong influence on our terrestrial environment. The extremely high temperatures emit high doses of x-ray and ultraviolet radiation. Within eight minutes, the x-ray and ultraviolet radiation reaches the Earth, causing instantaneous and abnormally high levels of ionization in the ionosphere, which consequently affects radio communications. Within about an hour, the highly accelerated high-energy solar protons traverse the vast distance from the Sun and slam into the Earth. Many of the high-energy particles are redirected by the Earth's magnetic field to the polar regions where they may penetrate to ground levels and cause a polar cap absorption event (or PCA). The unusually high proton density of the space environment at satellite altitudes are called

satellite proton events and are responsible for causing satellite communication disruptions and potential damage to satellite systems.

The massive explosions from flares may last from only a few minutes to many hours. The huge conservatively rated class X-15 flare of March 6, 1989 maintained its explosive power for ten hours, compared to the more typical 30 minutes for flares. It was an exceptionally powerful flare, perhaps the most powerful flare ever recorded.

Flares are not usually visible in white light. That is, we can't normally see flares with our naked eyes. The majority of light released by major flares occur in a region of the spectrum that requires a monochromatic light filter (such as an H-alpha filter) to be seen. Only in rare cases, during particularly intense flares, can they be seen in white light. These cases are reserved for the rogue flares, which superheat the photosphere and cause simultaneous brightenings of the photosphere. These brightenings can be seen in white light, but last only momentarily. Flares are therefore, not usually seen in white light since most flares do not attain the high temperatures necessary to superheat the photosphere to levels that can be detected in white light.

It typically requires approximately 36 to 48 hours for a powerful flare to produce significant geophysical events. By calculating the time it takes for flare-related impacts to affect the Earth, the velocity of the traveling solar material can be calculated. Generally, the higher the velocity of the material, the more severe the terrestrial impacts tend to be. Flares which eject matter at speeds sufficient to cross the sun-Earth boundary in 24 hours are capable of producing profound terrestrial effects. However, particle velocities are not the only aspects which must be considered. Interplanetary magnetic fields and plasma densities are also important factors, but will not be discussed here in any great detail. Suffice it to say that plasma densities (that is, the density of the cloud of material ejected by flares) that are relatively high tend to produce strong effects at the Earth. Likewise, the magnetic fields contained in the cloud of particles ejected by flares have effects on geomagnetic activity. Interactions between the Earth's magnetic field and the magnetic fields in the cloud of particles can cause field lines to couple, link and destroy each other. This process releases vast quantities of energy and heat into the Earth's atmosphere which causes both auroral activity and intense magnetic storms. More will be said on this in later sections.

2.5.4. Polar Cap Absorption Events

Perhaps one of the most astonishing influences of large solar flares are the polar cap absorption events (also known as PCA events or PCAs). PCAs occur shortly after the eruption of a powerful proton flare. The proton flare ejects large quantities of solar protons at high velocities towards the Earth. Within a few hours, these high energy particles arrive at the Earth. Since the particles which arrive at the Earth have an electrical charge, they are influenced by the magnetic field of the Earth. The Earth's magnetic field effectively steers the high-energy protons to the north and south geomagnetic poles. Here, the particles slam into the ionosphere at very high speeds. Their energy permits them to penetrate to deep levels in the Earth's atmosphere. As they penetrate, they collide with constituents of the Earth's atmosphere. When they do so, they ionize it. This ionization prevents radio signals from being reflected by normal ionospheric refraction. Hence, long distance radio communications are severely inhibited during PCA events over the polar regions.

The intense ionization which occurs during strong PCA events are usually confined to the polar regions. However, the latitudinal dependence of PCA-related ionization is strongly dependent on the intensity of the event. Particularly intense PCAs may cause radio blackouts for regions down to geographical latitudes of near 50°. Thus, middle latitude regions may also be affected by PCA events.

The intensity of PCA events is measured at polar stations using instruments called Riometers (Relative Ionospheric Opacity meters). These basically measure the transparency of the Earth's ionosphere. During PCA events, absorption of extra-terrestrial radio signals (i.e.,. cosmic noise) is enhanced and the corresponding decrease in signal intensities is recorded by this instrument. A PCA occurs when the absorption detected by the riometer exceeds 2.0 dB during daylight hours or 0.5 dB during the night. PCAs usually reach a peak absorption level soon after the flare and may require several days (perhaps up to several weeks) to return to preflare levels.

PCAs also produce ground level events (GLE), where the penetrating solar particles actually reach ground levels briefly over polar regions. These events are detected using instruments called neutron monitors. When the neutron monitor trace increases by 5% or more above normal background levels, a ground level event is said to be in progress.

Associated with GLEs are phenomena called Forbush Decrease Events (or Forbush Decreases). These events are also measured by neutron monitors and are defined when the neutron monitor trace decreases 5% or more below normal background levels. Forbush decreases and GLEs are usually associated with large geomagnetic storms (discussed in later sections).

2.5.5. Sweep Frequency Events

It has been known for years that the Sun emits radio waves over a wide range of frequencies. Although solar radio astronomy began in 1942, it never really became a serious area of research until after the second world war in 1945 and 1946. The years of research have yielded some interesting results, some of which we will examine in this section.

The Sun radiates three types of radio emission. (1) The constant background continuum of the quiet sun, observed throughout the radio spectrum, caused by thermal emission in the chromosphere and corona. (2) The slowly varying component, most readily observed at wavelengths of 3 to 60 cm. This component is associated with sunspots and plages. (3) The transient enhanced radiations, including noise storms and the several types of burst radiations.

The radio burst radiations which we will concentrate on in the following sections have specific characteristics that allow them to be separated into groups or types. We will concentrate on the radio emissions identified as Type II and Type IV sweep frequency events.

The term sweep frequency is used to describe the behavior of the radio emissions as observed at Earth. These emissions consist of intensified regions of the radio spectrum which drift (or sweep) from higher to lower frequencies. For example, during a major flare, a Type II radio sweep means that during the flare, part of the radio spectrum observed intensified (i.e., the noise became louder) and drifted from high frequencies down to lower frequencies. This is what is meant by a sweep frequency event.

There are basically five major types of radio emissions which are commonly categorized. These types are categorized using Roman numerals and depict different aspects and phenomena occurring on the Sun at radio wavelengths. The following sections very briefly cover the slowly varying component, as well as emissions of types I, III and V. A more extensive analysis of the slow drift bursts (types II and IV) will follow, as they pertain more to the occurrence of major geomagnetic storms than the other types.

References For First Half of Part I

[1] (1908) **On the probable existence of magnetic fields in sunspots.** *Journal of Astrophysics* #28, pg. 315-343.
[2] (1925) **The law of sunspot polarity.** *Journal of Astrophysics* #62, pg. 270.

(To be continued)

The 50 MHz DX Bulletin was founded by Harry Schools, KA3B. This special issue, consisting of a guide written by Dr. Cary Oler of Solar Terrestrial Dispatch, University of Lethbridge, Alberta, Canada was edited and and published by Victor Frank, K6FV. Comments may be sent to Sheldon Remington, PO Box 1222, Keaau, HI or to me at PO Box 762, Menlo Park, CA 94026.